

UNITED STATES AIR FORCE ARMSTRONG LABORATORY

Object Model Working Group Core Plan Representation

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September 1996

20000828 003

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TECHNICAL REVIEW AND APPROVAL

AL/HR-TP-1996-0031

This report has been reviewed by the Office of Public Affairs (PA) and is releasable to the National Technical Information Service (NTIS). At NTIS, it will be available to the general public, including foreign nations.

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FOR THE COMMANDER



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| REPORT DOCUMENTATION PAGE | | | Form Approved OMB No. 0704-0188 | |
|---|---|---|------------------------------------|---------------------------|
| Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503. | | | | |
| 1. AGENCY USE ONLY (Leave blank) | 2. REPORT DATE September 1996 | 3. REPORT TYPE AND DATES COVERED Final - February 1995 to September 1996 | | |
| 4. TITLE AND SUBTITLE Object Model Working Group Core Plan Representation | | 5. FUNDING NUMBERS C - F33615-92-D-1052 PE - 63106F PR - 2950 TA - 00 WU -43 | | |
| 6. AUTHOR(S) R. Adam Pease, Capt. Todd M. Carrico | | | | |
| 7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Teknowledge Corporation 1810 Embarcadero Road Palo Alto, CA 94303 | | 8. PERFORMING ORGANIZATION REPORT NUMBER | | |
| 9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) Armstrong Laboratory Human Resources Directorate Logistics Research Division 2698 G Street Wright-Patterson AFB, OH 45433-7604 | | 10. SPONSORING/MONITORING AGENCY REPORT NUMBER AL/HR-TP-1996-0031 | | |
| 11. SUPPLEMENTARY NOTES | | | | |
| 12a. DISTRIBUTION AVAILABILITY STATEMENT Approved for public release; distribution is unlimited. | | 12b. DISTRIBUTION CODE | | |
| 13. ABSTRACT (Maximum 200 words) The Core Plan Representation (CPR) is an effort to develop a plan representation which supports the representation needs of many different planning systems. The goal of this effort was to leverage command functionality and facilitate the reuse and sharing of information between a variety of planning and control systems. The CPR attempts to embody a standard which is general enough to cover a spectrum of domains from planning and process management to workflow and activity models. In addition, the proposed representation will be powerful enough to support complex, hierarchical plan structures. The prime motivation for the CPR effort is to address plan interchange requirements of several military planning systems. | | | | |
| 14. SUBJECT TERMS Air Force Logistics Core Plan Representation | | Object Oriented Programming Object Model Working Group | | 15. NUMBER OF PAGES 24 |
| | | | | 16. PRICE CODE |
| 17. SECURITY CLASSIFICATION OF REPORT UNCLASSIFIED | 18. SECURITY CLASSIFICATION OF THIS PAGE UNCLASSIFIED | 19. SECURITY CLASSIFICATION OF ABSTRACT UNCLASSIFIED | 20. LIMITATION OF ABSTRACT UL | |

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1. Introduction

The Core Plan Representation (CPR) is an effort to develop a plan representation which supports the representation needs of many different planning systems. The goal of this effort is to leverage common functionality and facilitate the reuse and sharing of information between a variety of planning and control systems. The CPR attempts to embody a standard which is general enough to cover a spectrum of domains from planning and process management to workflow and activity models. In addition, the proposed representation will be powerful enough to support complex, hierarchical plan structures. The prime motivation for the CPR effort is to address plan interchange requirements of several military planning systems, but this proposal attempts to go beyond military planning and present a more general plan representation.

This document is issued as a request for comments on the initial proposal. Feedback from the planning community is encouraged in order to help refine this design and broaden its acceptance.

In order to gain a full appreciation of the design, it is important to understand the design process of the CPR. Section 2 of this document provides information about history, processes, and plans for the CPR. It also includes reference to some of the research and development efforts which contributed to the current design. Section 3 provides an overview and then explains the design, incrementally adding pieces of plan information. A detailed description of the complete design is captured in Section 4, including class designs and descriptions. Section 5 provides a summary of conclusions..

Comments, questions, or pointers to additional relevant information would be greatly appreciated. All responses should be directed to Adam Pease at apease@teknowledge.com.

2. Background

The design of the CPR was derived from years of research and experience. This design attempts to unify the major concepts and advancements in plan and process representation into one comprehensive model. This section first provides some motivation for the CPR effort. Next, a significant design consideration is explained. References are then given for research efforts which had particular influence in the design process. Finally a notional schedule and process of the next stages of the CPR design are given.

2.1. Motivation

There are two significant payoffs to the CPR effort. The first is that creation of a base plan representation will facilitate information interchange among different planning systems. Imagine a generic military planning situation. A crisis develops and a joint task force is formed. The leadership and staff use a planning application to develop guidance for their subordinate commands. This guidance includes

background on the situation, objectives which must be met to contain the crisis, constraints on the actions of the task force and high level specification of the schedule of operation. This information is passed to individual commands which have specific requirements and methods of planning. A standard plan framework enables improved information transfer to these specialized planning applications. Continuing to follow this generic and hypothetical example, the commander of the air component of the task force and his staff will use their superiors' objectives to develop more detailed objectives, lists of targets which support those objectives, and then repeatedly create a schedule of aircraft sorties to destroy those targets. Pilots flying those sorties could benefit from performing simulated runs. A core plan representation enables information from the plan to be transferred to simulation entities possibly allowing a single pilot to fly along side computer generated forces simulating the other pilots in his flight. While information transfers of this sort will rarely be complete, and will often require further augmentation and elaboration for the new application, the CPR will reduce the amount of manual rekeying and reformulation of existing data.

The second payoff is in the creation of common services based on the CPR. There are two broad areas of services with immediate utility. The first area is visualization. Manufacturing, business planning and construction management all share several basic forms of visualizing plan information. The CPR enables creation of these common views which will dramatically reduce implementation time for specific systems. Well designed common viewers can then be specialized for particular planning applications instead of written from scratch. The second area is scheduling. Many important advances have occurred in the operations research and artificial intelligence communities which allow software systems to provide significant aid in complex scheduling problems. A complete scheduling system can rarely be build on generic techniques alone, but the CPR enables the creation of generic scheduling tools which eliminate the need to build these tools from scratch each time a new scheduling domain is targeted.

2.2. A Design Objective

The CPR attempts to model the "basic level" [Rosch, 1976] of plan representation for the given domain of planning needs. The basic psychological level is a simple yet elegant concept. In an ontology of several levels describing a given domain, there is one level at which humans associate the largest amount of information. For example,

| | | |
|---------------|-----------|-----------|
| SUPERORDINATE | ANIMAL | FURNITURE |
| BASIC | DOG | CHAIR |
| SUBORDINATE | RETRIEVER | ROCKER |

Table 1 : Example from [Rosch, 1976]

There are several attributes of the basic level. One is that this is the level at which terms are used in neutral contexts. For example [again after Rosch] *There is a dog on the porch* as opposed to *There's a*

mammal on the porch or *There's a wire-haired terrier on the porch*. The latter two sentences are unusual and require further explanation.

For plan information, simply specifying objects Entity and Relationship is not enough. Nor would defining Plan as an object without attributes be sufficient. On the other hand, specifying the Plan as having weatherForecast attribute, or defining a NonshareableResourceConstraint would be too specific. Few plans require this sort of information. The CPR specifies plan information at the lowest level common to all planning systems of interest.

It should be noted that the basic level is specific to the domain being covered. If the context of interest is air campaign planning then a weather forecast object is useful and the CPR must be specialized for that context. The CPR may be specialized to cover more restricted domains in greater detail. The basic level of plan information for air campaign planning will contain a much richer set of information than is common to planning in general.

2.3. Prior research

Planning is a fundamental component of intelligent behavior. The discipline of planning has been studied for generations in an attempt to produce more effective plans. Modern developments and techniques from the fields of artificial intelligence, operations research, management, decision theory and philosophy have all been applied to planning problems.

Planning may also be seen to include that which AI researchers have separately termed scheduling. While the CPR is targeted to address the representation needs of both planning and scheduling, the two areas are given the following definitions in AI

Planning - Specifying a set of actions in order to meet a set of goals or objectives

Scheduling - Resolving the dependencies among actions and resources in a plan to specify amounts of resources used over time and times at which actions will take place.

Planning is a significant area of research within artificial intelligence. A review of this broad field is outside the scope of this document. The interested reader is referred to [Tate et al, 1990] and [Allen et al, 1990]. Scheduling has a significant body of literature as well. For this, the reader is referred to [Zweben and Fox, 1994].

Two efforts in particular have influenced the CPR. KRSL-Plans bears many similarities to CPR. In fact, some of the same people working on KRSL-Plans have contributed significantly to the CPR design. The goals of the two efforts are slightly different however. While KRSL-Plans is working on developing an ontology of plans and activities, CPR is striving for an object oriented software design developed with a strong ontological awareness. It should be noted that KRSL-Plans like CPR is also an ongoing effort

although it began much earlier. I-N-OVA [Tate, 1996] is another ongoing effort which bears some similarity to CPR due to the significant contribution of Austin Tate to the CPR effort.

2.4. *Process and Schedule*

The CPR design effort was begun in May of 1996. Background was collected and a "strawman" design was created. This information served as inputs to a Core Plan Representation meeting held July 15-16, 1996. Members of the meeting included ARPA researchers working on planning and ontology issues. Many had also created major planning systems. Also in attendance were software developers for the JTF-ATD [Hayes-Roth and Erman, 1994] [Hayes-Roth, 1995] [Carrico, forthcoming] and Air Campaign Planning Tool who are creating planning systems as part of those efforts. This meeting yielded progress on many ontological issues related to the CPR and on improvements to the design. Design discussions with members of this group are ongoing. A second group meeting was held on August 6th with ARPI researchers some of whom were present at the July meeting. This second meeting yielded additional progress principally on ontological issues but also on the design.

This paper will be presented at the ARPI quarterly meeting on September 24th.

The short term goal of the CPR effort is to develop an initial design which can be implemented and tested during the 1996 fiscal year. The long term goal is to obtain wide scale acceptance and use of the CPR, and seek sponsorship to make it an industry wide commercial standard. A tentative schedule of future activities can be found in Table 2. Though the dates are subject to change, the milestones should provide insight into the time frame and process being pursued. The general process is to seek design feedback during an initial review period, then freeze the design for a period of time, during which the design will be implemented and tested in one or more real application domains. As the design stabilizes, the process will alter focus from design to implementation evaluation. This test implementation is likely to involve the JTF-ATD and JFACC programs, two premier military planning applications. Additional non-military applications may also be considered. Based on the feedback from the implementation test, additional changes and expansion of the design will be considered. After the revised design is worked through, there will be another general request for comment as a precursor to application for standards acceptance. After that proposal review period, adoption as an official DoD standard will be pursued.

| Date | Milestone |
|---------|---|
| Sept 96 | Initial draft release of the CPR design for general review and comment. |
| Dec 96 | Final draft release of the CPR design for general review and comment |
| Mar 97 | Initial experimental implementation of the CPR design |
| July 97 | Official standards proposal release, final request for comments |
| Sept 97 | Target standards acceptance date |

Table 2 : CPR Milestones

Though the timetable is extremely short, the history of design and development efforts in which the CPR is rooted provides a sound foundation. The near term application of the design in an ongoing implementation effort should identify any relevant application issues. Finally, the ongoing support and guidance from the combined knowledge and experience of the members of ARPI should provide added assurance of timely progress.

3. Building the CPR

To develop an appreciation for the proposed CPR design, some of the component objects will first be presented. The plan representation will be constructed piecemeal in order to capture the design motivations, considerations, and open design issues. Finally, all the components will be brought together to form the complete core plan representation. Readers who are only interested in the finished design may skip to Section 4.

3.1. Foundation Concepts

The first step is to show the minimal concepts necessary to represent any plan. This draws on the work KRSL, the POCG, and O-Plan [Tate, 1994]. The initial concepts are Action, Actor, Objective, and Resource. An Action is performed by an Actor. The motivation behind performing the Activity is to accomplish some Objective. In performing the Action, the Actor may utilize a Resource. An Actor in one Activity could be a Resource in another.

Next, input from the workflow and manufacturing communities suggests that plans must be situated in time. TimePoint object is therefore added to the our minimal set. The TimePoint represents

some association of the Action with time. In considering the temporal reference of the Activity, it is only natural to then consider the relevance of the spatial references. A SpatialPoint is added to the minimal set. As with TimePoint, SpatialPoint has the capability to represent an exact location, or a vague area. It is capable of grounding the objects both in absolute and relative terms.

In considering the representation of relative SpatialPoint, as well as the association of Resources with the plan, it appears that relation needs to be added our minimal set. Relation is an association between elements of this set, including self association. Further, relations are valid between most sets of objects.

The minimal set is shown in figure 3-1. This is the set of core conceptual pieces from which CPR representation will be constructed.

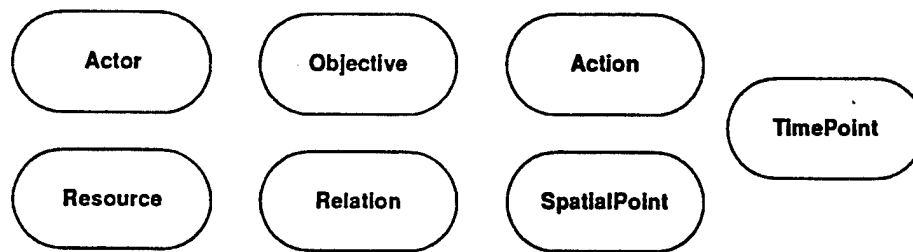


Figure 3-1 : Basic Concepts

It should be emphasized that the idea is not necessarily to instantiate the objects of the core, but rather use them to better understand the essence of a plan. If, in designing the representation of the plan, it is beneficial to use these notional objects as parents in the object trees, then all the better.

At this point, many other planning components could be considered, but most can be successfully mapped into one of the existing core elements, or a combination of the core elements. As building blocks, it is acceptable that some plan element mappings are not a one-to-one mapping to elements in the core. The critical issue at this point is that a mapping exists for all important elements of a plan.

With the core in place, the job of constructing the CPR can begin.

3.2. From Concepts to Design

It is now time to create the basic structure of the plan from the building blocks given above. No attributes and methods are considered yet. A Plan consists of one or more Actions performed in pursuit of some Objective. As noted above, Actors may use Resources in the performance an Action. Under closer scrutiny, it appears that Actor and Resource are not directly elements of the Plan, but rather of the Activity itself. The design now appears as in Figure 3-2.

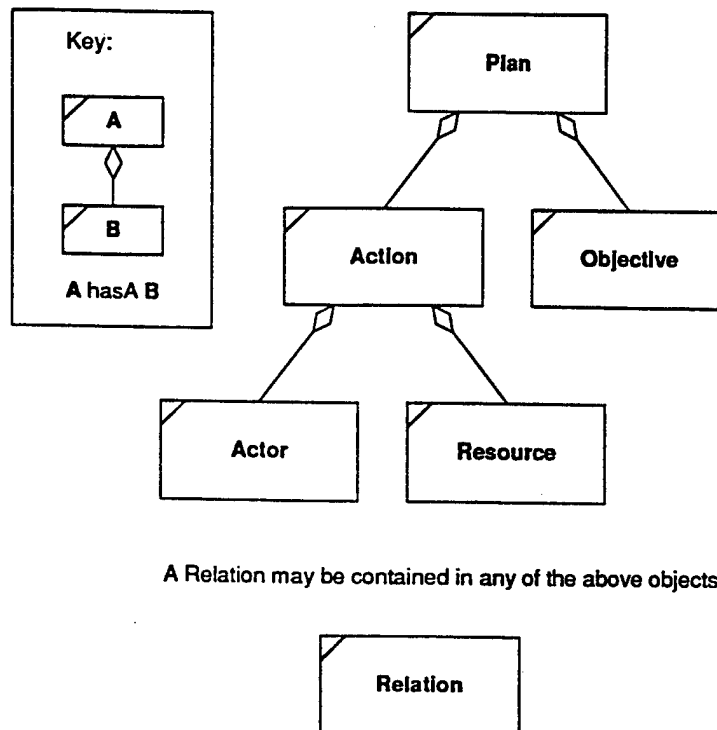


Figure 3-2 : Initial Framework

It is clear that from this basic framework that a host of other required elements could be identified and added. Because the CPR was meant to be a general purpose, flexible representation, an extremely complex or constraining design is inappropriate. To that end, elements are carefully considered for both relevance and generality before being added. The next step is to review the core and identify where the remaining basic concepts reside.

TimePoints are associated with the Activity, and help ground the actions to be performed. Though a number of TimePoints may provide information about an Activity, every Activity has at least a beginning and end, though either may be infinite or periodic. While SpatialPoint is information which will often be present in a particular plan representation, it is not present in the CPR. The CPR represents a minimal set of information common to all plans. Since spatial information is not present in many plans, this information was dropped from the CPR and will be left for specializations of the CPR to instantiate.

Due to aggregate nature of Plans, it is appropriate to allow a Plan to be associated with another Plan, where one would represent the parent plan and the other a sub-plan. A similar argument may be made for both Objectives and Actions, representing sub-objectives and sub-actions respectively. During execution of the Plan, Objectives are reviewed in order to gauge the effectiveness of the Plan and identify when the Plan is complete. This review is performed against a set of evaluation criteria relevant to the Objective. The entity EvaluationCriterion was added to Objective address this need.

Constraints and Uncertainty are other elements essential to planning. Relations are in fact Constraints on a pair of objects. Constraints capture conditions placed on Activities or Objects. Uncertainty captures the degree of confidence in information. Constraints and Uncertainty have no single place in the CPR where they would be most appropriate. As such, they are left as objects which can be contained in any object of the plan.

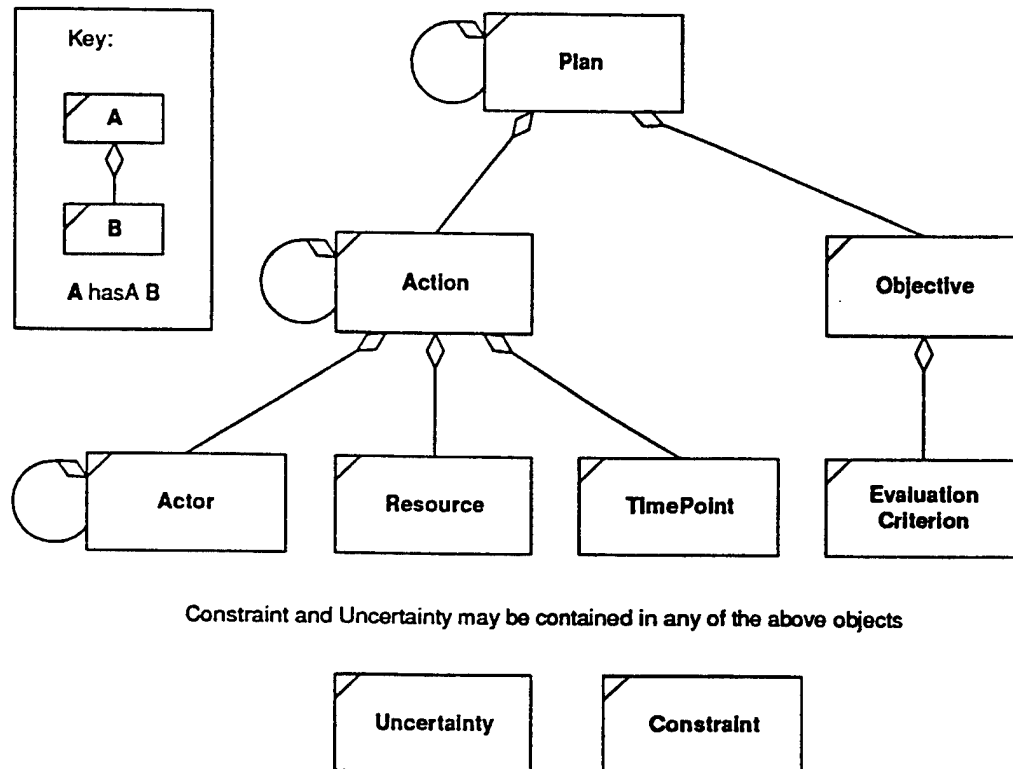


Figure 3-3 : The Revised CPR Framework

The framework is now complete although some additions and specifics remain. This framework is shown in Figure 3-3.

A set of design issues relevant to this framework have been collected, and are listed in section 4.1 below.

3.3. Completing the Design

Now a final pass can be performed, bringing together the last remaining pieces and adding an initial set of attributes and methods. This section attempt to step through that progression. Attributes which are plural may be understood as containing a list of objects.

First, Plan needs to be completed. It already contained subPlans, Actions, and Objectives. It needs a name, currently of type String. Additionally, it must have a set of metadata describing the merits of one plan relative to others. This is contained in the attribute evaluation. The class Annotation is created to maintain general Plan metadata. It is also valuable to allow metadata about the status of plan creation. For

this purpose, the issues attribute is added. Finally, alternative plans, if available, should be accessible from the current plan. To support this, the attribute alternative is defined as a list of Strings.

Action may now be elaborated. Action requires a name, similar to Plan. We have already identified subActions, actors, resources, and begin and end TimePoints. PlanObjects are defined to represent entities referred to in an Action which are not the Actor or a Resource. For example, the recipient of a mail message would be recorded as an instance of PlanObject.

It is clear that most plan objects require a name. This attribute is added to Plan, Action, Actor, Resource, Constraint, and Annotation. Many of the other objects, like Objective, Imprecision, and Uncertainty, have types or names as well, therefore a name field is added to each, currently of type String. Future iterations of the CPR may attempt to enumerate the allowable types, but this is left unspecified at this time.

Actors may have objectives of their own and so a reference to the plan objectives is added and called objectives. Since the Actor may not be a single person, but represent an aggregate of some kind, the attribute subActors was added.

Objective contains type, subObjectives, and evaluationCriteria. It requires some additional work. To Objective, value is added to hold the actual objective element, represented as a String. Objective also references the list of Actions in the Plan which are meant to satisfy it.

Constraint currently holds only name. In order to complete Constraint, additional fields are added to hold the terms of the constraint expression, any associated subConstraints, and the constraint's levelOfHardness. These are represented as attributes of type String, Constraint, and Integer respectively. Level of hardness represents a relative priority for the various constraints in a plan.

Annotations consist of a String name and the body of the annotation. In addition, the annotations could be constructed hierarchically to form linked documentation, and thus a list of subAnnotations is required.

Uncertainty and Imprecision are both required but different plans may have very different requirements for handling them. There is an understanding that each would have a type, a measure, and a source, but the latter two do not have a clear, common representation. As such, they are currently left undefined.

Assumptions are currently represented as the assumption data, and triggers which identify when that assumption data becomes invalid and what to do when that condition occurs. The trigger is therefore a condition-action pair but again, a common representation is most likely not possible and it will remain to specializations of the CPR to instantiate their specific requirements.

Finally, some additional components were identified, but require additional consideration. The first is Fact, which is a basic data component having a String name and a list of terms. The second is a Frame, which consists of a set of attribute-value pairs.

The next section presents the final design, including details about each component.

4. The CPR design

The CPR design addresses the level of highest possible value, utility and commonality for information interchange and the development of common services. Many details must be left unspecified because committing to a specific design detail would prevent common description between different planning applications.

In most design efforts decisions and tradeoffs are made and not recorded. Subsequent design efforts do not have the advantage of reusing or being influenced by the designs which were not chosen as well as the positive products of a design. Each new design must largely start from scratch. The CPR effort has taken the opposite approach. Whenever reasonable choices are encountered, they are recorded.

The CPR design is presented in several sections. The first gives an overview of the basic design. The second raises a series of issues which either illustrate reasonable alternatives to the current design, or describe items which remain unresolved. The third section presents the detailed description of the CPR, with discussion of the components and their design rationale.

Core Plan Representation Design

Version September 12, 4:00pm

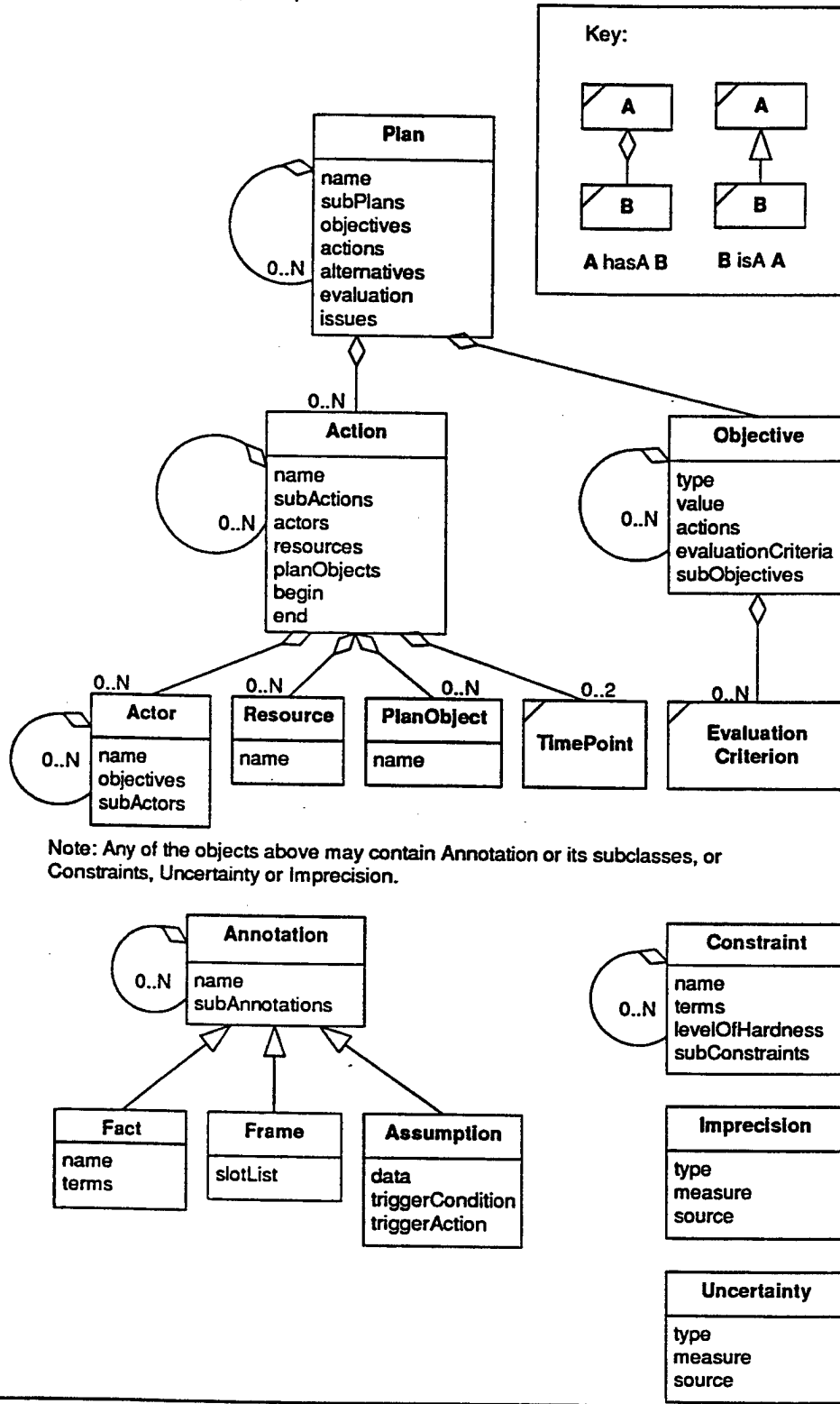


Figure 4-1 : The CPR Design

4.1. Design Tradeoffs and Issues

Some of the design issues were presented briefly in section 3, but are presented again here for completeness.

1. **Action linking.** Action could have a slot which would be a relation to another action. This would be very useful in plans which have partially ordered sequences of actions. However, an ordering constraint is just one type of constraint, so a scheme where ordering constraints are represented like any other constraint can be considered more general.
2. **Action begin and end times.** These times could be viewed as constraints since they are often not absolute times. There may be justification not to specify how Action will use begin and end. For example, some Actions are continuous, periodic, or intermittent and don't clearly have a beginning or ending. Possibly having a timeSpecification attribute would be an improvement.
3. **Actions could also have priority and sequence items like ACPT.** These are constraints so in the minimal CPR model they are not explicit attributes of Action but would be modeled as instances of Constraint.
4. **Actor types.** One alternate approach would be to have different types of Actors. We could have Actors who carry out Actions, Actors who are influenced by Actions, or Actors who are responsible for a Plan. Currently, the CPR models the first case only as Actors. In the second case, the entity may be specified as a Constraint on an Action or as simply a Annotation. In the third case a planner would be an Actor in a workflow Plan which specifies the creation process for a Plan. Or that entity might be given as a Fact on a plan with author as predicate and the entity's name as the value of the predicate. One option would be to specify Actors which are not carrying out Actions as PlanObjects (see PlanObject below).
5. **Linking Actors and Actions.** At the ontological level, Actions are carried out by Actors and so in an entity-relationship diagram we definitely need a link "carried out by". At an object oriented design level however we have additional factors such as software modularity and maintainability to consider. These factors bias in favor of minimizing the number of linkages between modules. We could
 - a) Have a link (pointer) from Action to Actor and vice versa
 - b) Have a string "key" and a service of Plan which retrieves an Actor or Action based on that key. Actor would contain a list of keys for the Actions it performs.
 - c) Have relationships between Actors and Actions given in Constraints, and have the Constraints reference the string keys.
 - d) Have the Constraints contain pointers. The CPR currently just has Actions contain Actors. If Actors needed be retrieved directly, this would require a search service on Plan.
6. **Assumptions, Monitors and Triggers.** A capability to enter the assumptions on which aspects of the plan depend is necessary. Also needed is a hook to have a specified action take place when that assumption changes. A minimal solution would be a user interface which enters assumptions into the plan as Annotations attached to the relevant part of the plan. The same interface would also list all the current assumptions in the plan. Those assumptions could have additional Annotations which specify what action to take if the assumption changes. A more sophisticated solution would be to specify and supply monitor and trigger services and allow the specification of a workflow describing what actions to take should an assumption change.

7. **Action and Plan status.** Representing status is potentially a very complex problem. There is a need to represent the status of individual Actions, the aggregate status of a Plan and the status of the context in which the Plan exists. This is a significant omission in the current version of the CPR. There needs to be a coherent expression of all dynamic information related to the Plan. This includes Plan and Action status and information about the situation. This design will involve working with situation description designs like the JTF ATD situation server to determine an appropriate partitioning.
8. **Do Actors need to have roles?** Is role an attribute or a class? Is there a need to place Actors into groups? Is the current hierarchical structure of Actors and sub-Actors sufficient?
9. **Plan attributes - subPlan and alternatives.** SubPlan is an ontologically non-minimal attribute. Here is another issue which straddles the fence of philosophical purity vs implementation effectiveness. While a really huge plan could be encoded all as one plan, there is value to the user in splitting it up into manageable sections. Microsoft Project for example allows the user to have multiple projects which are linked together. Each one is self contained yet can link to the others. The same concept is in the CPR.
10. **PlanObject superclass.** PlanObject could be seen as a fundamental object type with possible specializations to Resource and Actor (performer of actions) and other agents. This might give an extendible framework for the CPR and allow a relationship to several existing workflow standards more easily. Specifications of PlanObjects could be created that perform certain roles in the plan, such as performing an action as an actor or being created/modified or used as a resource. However, this issue does beg the question of what common state or behavior does a PlanObject embody.
11. **Constraints vs. Facts.** Constraints are envisioned as allowing variables in the terms. Facts would not allow variables. However, a completely specified Constraint is just a fact, and there's no reason why a Fact can't specify incomplete information. A Constraint could be viewed as an object with a dynamic function in automation. That is to say Constraints would be updated by a constraint resolver whereas Facts are intended to hold information entered by the user and not modified by the system. This is probably a poor distinction however, since ideally the same objects should be usable by human or machine in a seamless fashion.
12. **Location of Constraints.** One possibility would be to place all Constraints under Plan and simply have them refer to objects they constrain by a String key.
13. **Resources.** There may be a reasonable attribute to include here. Doesn't every Resource have some measure of how much of it there is and how much of that is being used or consumed?
14. **Plan decompositions and Objectives.** SubPlans and Actions are alternatives for decomposing plans and the conjunct of both is the complete decomposition of a Plan. There are several alternatives for how to relate Objectives in a subPlan with its parent Plan.
 - a) The objectives in a subPlan must be specializations of Objectives in the parent Plan.
 - b) The Objectives in a subPlan must be specializations or orthogonal to the Objectives in the parent Plan.
 - c) The Objectives in a subPlan may override the Objectives of the parent Plan much like subclassing in an object oriented language. The Objectives in the subPlan are true for the subPlan and the Objective in the parent Plan are true for the parent Plan. When Objectives in the subPlan and parent Plan are in conflict,

the resolution is undefined. The anomalies are flagged for user or system resolution on a case by case basis.

15. **Action vs. Plan.** An Action in one context could be seen as a Plan in another. Both can be decomposed. Possibly they should be the same class or derived from a common superclass.

4.2. Detailed Design - Class Descriptions (alphabetical list)

Action

```
name          : String
subActions    : List of Action
actors        : List of Actor
resources     : List of Resource
planObjects   : List of PlanObject
begin         : TimePoint
end           : TimePoint
```

Action contains a name, possibly a set of decompositions, the resources used in carrying out the Action, any PlanObjects may be involved or the object of the Action and the times at which the Action begins and ends.

Actor

```
name          : String
objectives    : List of String
subActors     : List of Actor
```

An Actor is the subject of an Action. The Actor may have Objectives which drive the Actions it takes. Currently this is just a String pointer to an Objective in the Plan. There might be utility in having an Actor contain its own Objectives which are not directly Objectives of the Plan. SubActors is designed to hold aggregates of Actors like an organizational division in which the division acts together but where there is still a need to record information about the individuals who may act by themselves for other Actions.

Annotation

```
name          : String
subAnnotations : List of Annotation
```

An Annotation is designed to hold any type of unstructured data, paragraphs of text, pictures, video etc. It exists to hold any information which supports understanding or maintenance of the plan but it not strictly part of the plan itself. Note: This was previously called PlanDataElement.

Assumption

```
data          : (undefined)
triggerCondition : (undefined)
triggerAction  : (undefined)
```

An Assumption is intended to identify any information on which the plan information depends. TriggerCondition describe what kind of change in the data will activate the triggerAction. TriggerAction will specify the action to be taken if the data changes according to the triggerCondition. This object is a weak link between the CPR and dynamic entities which provide data on the current situation. More work needs to be done to determine what the best linkages are and how to integrate situation status and plan status.

Constraint

```
name          : String (a predicate name)
terms         : List of String (terms for the predicate)
levelOfHardness : Integer
SubConstraints : List of Constraint
```

This object holds any formal restrictions on an entity in the plan. Name and terms hold the expression of the Constraint, for example before(action1.begin,action2.begin) or greaterThan(numberOfTanks,100). LevelOfHardness describes how strict the Constraint is. Is the Constraint an absolute, or is it simply guidance which may be overridden if necessary? This may be too specific. Also, specifying the level as a number is probably too weak. What would most likely be needed would be a partial order on an ontology of Constraints indicating which Constraint would take precedence over another.

EvaluationCriterion

This object currently has no attributes. While there is a general need for Objectives to have evaluation criteria, it is believed than any further specification is too specific for the CPR. Specializations of the CPR however, will subclass useful specific versions of EvaluationCriterion.

Fact

name : String
terms : List of String

A Fact is one very general specification of a structured unspecified data element. It is supposed to handle information like hasCar(john), likes(Mary, Bob). It is really only useful as a way to exchange information between planners when there is not a direct corresponding slot for structured information.

Frame

slotList : a List of (Attribute, Value) pairs

Like Fact, this object is a very general specification of a structured unspecific data element. It is really only useful as a way to exchange information between planners when there is not a direct corresponding set of slots for structured information.

Imprecision

type : String
measure : (undefined)
source : (undefined)

The Imprecision object holds a measure of the imprecision or fuzziness [Zadeh, 1978] associated with a piece of information. There are different possibilities for an imprecision measurement. We might have simply a linguistic variable, or a linguistic variable with an associated fuzzy membership function. Drawing on endorsement research [Cohen, 1985], we might add an attribute for the source of the imprecision. There might be imprecision due to the measurement equipment, or perturbations in the transmission of information for example.

Objective

type : String
value : String
actions : List of String
evaluationCriteria : List of EvaluationCriterion
subObjectives : List of Objective

Objectives may also contain subordinate Objectives. The current idea is to place Objectives under Plan and have them point to the Actions which are designed to satisfy them. The pointer is currently just a String which may not be the best design.

Plan

name : String
subPlans : List of Plans
objectives : List of Objective
actions : List of Actions
alternatives : List of Strings
evaluation : Annotation
issues : List of Annotations

Plan is the aggregate object of this representation. SubPlans are Plans into which this top level Plan may be elaborated. Actions specify in detail how the Plan is accomplished. Alternatives is a List of Strings which refer to Plans which accomplish similar things. This is probably not the best way to represent this. Alternatives occur in several areas of the Plan. There may be several related Plans which all belong at an equal level in a hierarchy. Possibly some higher level object is required. Evaluation is an Annotation describing the merits of this Plan relative to other Plans. This is different from an EvaluationCriterion which describes how well a Plan is meeting a specific Objective. Issues is a List of Annotations which describes areas of the Plan which a planner (human or machine) needs to record as being incomplete or in question.

PlanObject

name : String

PlanObject is intended to contain information about an entity which is referred to in the description of an Action which is not an Actor or a Resource. It is helpful in creating a correspondence with the design of PIF.

Resource

name : String

There are all sorts of useful specializations of Resource. They are currently believed to be too specific for inclusion in the CPR.

Uncertainty

type : String
measure : (undefined)
source : (undefined)

The Uncertainty object holds a measure of the uncertainty associated with a piece of information. There are many possibilities for an Uncertainty measurement. A Bayesian [Feller, 1957] scheme might have a single real number, a Dempster-Shafer [Shafer, 1976] scheme two numbers, a simple certainty factor method might have a single integer, an endorsement scheme [Cohen, 1985] might have an enumerated type. Drawing on endorsement research, we might add an attribute for the source of the uncertainty. There might be uncertainty due to unreliability of the source, or of predication of a future event for example.

5. Conclusion

This proposal has provided references to planning research and suggested the need for a common, unified representation of a plan. Basic plan concepts were offered, concepts were assembled into a design framework and then refined. Design issues regarding this proposal were raised, many with suggested resolutions.

Comments, concerns, or deficiencies should be submitted to Adam Pease at apease@teknowledge.com. Input will be valuable at any time, but to influence the ongoing design effort, comments are best submitted by November 30th, 1996.

5.1. Acknowledgments

The work presented in this proposal is the combination of many areas of research, design, and implementation. Austin Tate has provided extensive advice and criticism throughout the development of the CPR. Thanks are also due to CPR meeting attendees from July 15-16, 1996, and members of the ARPA Plan Ontology Construction Group. Rick Hayes-Roth brought his vision of the JTF Schema together with many years of experience to provide valuable guidance and input. As chief architect of the JTF ATD, his unique perspective on both design and implementation proved invaluable. Special thanks are due to John Schill and Lou Hoebel whose financial support and encouragement made this proposal possible.

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7. Abbreviations

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|---------|--|
| ACPT | Air Campaign Planning Tool |
| ARPA | Advanced Research Projects Agency |
| ARPI | ARPA/Rome Lab Planning Initiative |
| CPR | Core Plan Representation |
| DoD | Department of Defense |
| I-N-OVA | Issues - Nodes - Orderings/Variables/Auxiliary |
| JFACC | Joint Forces Air Component Commander |
| JTF ATD | Joint Task Force Advanced Technology Demonstration |
| KRSL | Knowledge Representation Source Language |
| OMWG | Object Model Working Group |
| O-Plan | Open Planning architecture |
| POCG | Plan Ontology Construction Group |